

Motion Imaging and Tracking Acquisition System MITAS

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ABSTRACT

ATD thoracic displacements have been traditionally measured by mechanical systems with potentiometers actuated by strings in earlier embodiments, and rigid links in more recent versions. Due to the inherent limitations of these systems, a need exists for an advanced thoracic displacement measurement system that provides improved performance. The Motion Imaging and Tracking Acquisition System (MITAS) uses three linear array sensors, where each sensor serves to measure the angle between a plane containing a target LED and its own optical axis. The position of the target LED is determined by triangulation. Several target LEDs may be identified and tracked based on the real-time kinematics of the images projected on the sensors. The performance of MITAS was demonstrated during two series of dynamic tests and compared to mechanical measurement system. The MITAS has a higher bandwidth response to thoracic displacements than its electromechanical counterparts. The MITAS measured displacements, in general, corresponded well with the mechanical system measurements.

INTRODUCTION

Anthropomorphic Test Devices (ATD) are commonly used to quantify the injury potential of motor vehicle crashes. Studying the thoracic deflections of an ATD yields significant information pertaining to the effectiveness of restraint systems, including seat-belts and airbags. The two principal criteria for assessing potential injury levels of the thoracic region are chest deflection and viscous response.

ATD thoracic displacements have been traditionally measured by mechanical systems with potentiometers actuated by strings in earlier embodiments, and rigid links in more recent versions. The current National Highway Traffic Safety Administration (NHTSA) THOR ATD, for example, utilizes articulated rigid links with precision potentiometers at the articulations. While this system has been found to be satisfactory, some limitations, however, have been noted. These include irreducible play in the linkage, need for knowledge of precise pre-test potentiometer position, and the incursion of the linkage into the abdominal space required for other purposes. Consequently, a

need exists for an advanced thoracic displacement measurement system that overcomes these limitations and provides improved performance.

To meet this need, Conrad Technologies, Inc. (CTI) conceived the Motion Imaging and Tracking Acquisition System (MITAS) and conducted research and development of the underlying technologies. MITAS comprises three linear array sensors, each serving to measure the angle between a plane containing a target LED and its own optical axis. With three such sensors arranged appropriately, the position of a target LED is determined by triangulation. When several targets are present, tracking algorithms identifies them.

Under NHTSA's sponsorship, this report describes efforts to establish the suitability of MITAS as a thoracic deflection measurement system for the THOR ATD. More specifically, the objective of this effort is to develop an advanced, non-contact, thoracic deflection measurement system for retrofit to the existing 50th percentile male THOR ATD. Eventually this system may also be adapted to the 5th percentile female THOR ATD presently under development for the NHTSA.

MITAS provides improved performance over the traditional mechanical systems. Furthermore, the cost of a production system is anticipated to be low enough that it would be suitable for routine use in crash testing.

BACKGROUND

Prior art for measuring thoracic deformations of a dummy is extensive. It includes a very early system (McElhaney et al., 1973) utilizing a mechanical linkage between the chest wall and the vertebral column with potentiometers at the pivots. This was soon followed by the Hybrid III Standard Chestpot (Foster et al., 1977) in which one end of a mechanical link is coupled to the sternum through a sliding joint and the other end is attached to the shaft of a potentiometer mounted on the thoracic spine. Motion of the sternum produced a rotation of the potentiometer leading to a change in an electrical signal. Later embodiments incorporated deflection measurements at four points on the chest plane, located approximately at the four junctions of the second and fifth ribs with the sternum. Also, later embodiments eliminated the mechanical link and sliding joint by using spring tapes or string pots in various ways.

Shortcomings of electro-mechanical systems arise from the fact that they are contact systems, requiring a physical connection of the two points between which measurements are made. This physical connection is constrained by the requirement that the act of measuring does not adversely effect the measurement itself. String pots impose unwanted spring forces and inertia loading on the chest wall. Also, while the transient response of a string pot improves with increasing stiffness of its retracting spring, the unwanted spring force on the chest wall also increases. Consequently, measuring fast transients with string pots always involves some form of tradeoff in the response. This is particularly acute in situations when the chest wall begins to move rapidly, as for example, after contact with a deploying airbag. The response for such fast transients has been found to be unacceptably poor. Further, the signal to noise ratio of electrical signals developed from a potentiometer generally degrades with use because of mechanical wear. Additionally, mechanical systems also suffer from dead zones, play and backlash in the linkages.

More importantly, the two principal criteria for assessing potential injury levels are the chest deflection and the viscous response, the latter being the numerical product of deflection and the velocity with which the deflection occurs when a test dummy is in a crash environment. From position measurements, deflection of the chest wall can be readily obtained, but finding its velocity requires differentiation of the positional time history signal. Any noise in the signal, including those due to artifacts arising from mechanical play, stick-slip or backlash, will significantly reduce

the usefulness of the velocity history obtained by differentiation. Also, for the most part, filtering of the signal has not been found to improve the results.

In MITAS, a linear CCD sensor array serves to measure the angle between a plane containing the target LED and its own optical axis. With three such linear array sensors arranged appropriately, as shown in Figure 1, the position of the LED is determined by triangulation. When several target LEDs are required, the targets are identified by tracking algorithms based on the kinematics of the images projected on the CCDs.

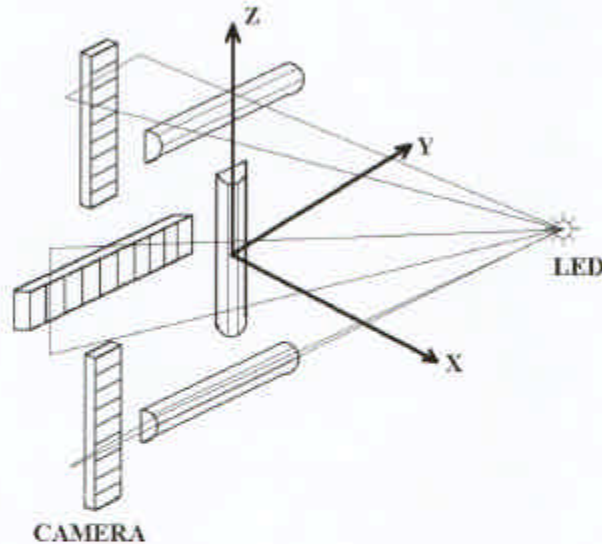


Figure 1. Arrangement of three linear CCDs and cylindrical lenses for tracking an LED target.

FIELD OF VIEW

Field of View (FOV) is defined by the range of motion of the LED targets on the thoracic surface and the fixed position of the array of sensors on the spinal column. The locations initially selected for displacement measurement are symmetrically situated about the mid-sagittal plane. Referring to Figure 2, four of the targets are located at the left and right attachment points of rib 3 (targets 1 and 3) and rib 6 (targets 5 and 6). Target 2 is centrally located between the attachment points of rib 3. Target 4 is centrally located between the attachment points of rib 4. Targets 1 through 4 define the thoracic surface. Targets 5 and 6 locate points of interest below the sternum.

Because of obscuration due to the upper abdominal cavity bag in the THOR ATD, all six targets cannot be seen simultaneously from any one viewing point in the thoracic cavity for the entire range of motion expected in testing. Consequently, the final design for the THOR ATD would feature two MITAS sensors arranged symmetrically on each side of the spinal column. In this report, the results of testing a single sensor array and data acquisition system are featured.

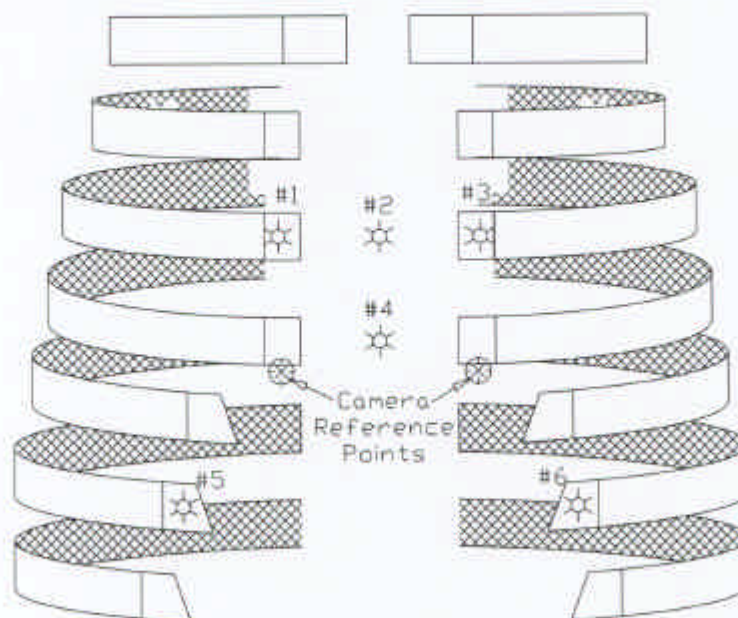


Figure 2. THOR ATD MITAS target locations

Both sensor arrays will image targets 2 and 4, for part of the full-scale range of motion and provide redundant measurement. The dual arrays will fit within the space normally occupied by the Crux system. These left and right sensors will be mounted on the upper thoracic column, above the articulation for posture setting, but with their optical axes close to the center of the articulation.

STATIC TESTING

The MITAS was utilized to triangulate a light-emitting diode (LED) at multiple positions while mounted on an X-Y-Z calibration table (Figure 3). The plots in Figure 4 illustrate the typical results obtained. Each plot represents the X, Y or Z distance fixed with respect to the sensor array and then a series of 1,000-inch linear translations along the axes perpendicular to the fixed distance axis. The points (\diamond) given in the plots represent the desired translation and the data label ($\pm i, iii, \pm j, jjj$) gives the computed triangulated translation.

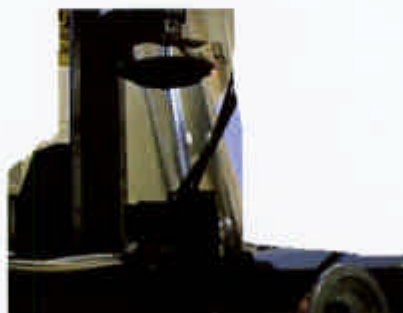


Figure 3. Static Testing on XYZ Table

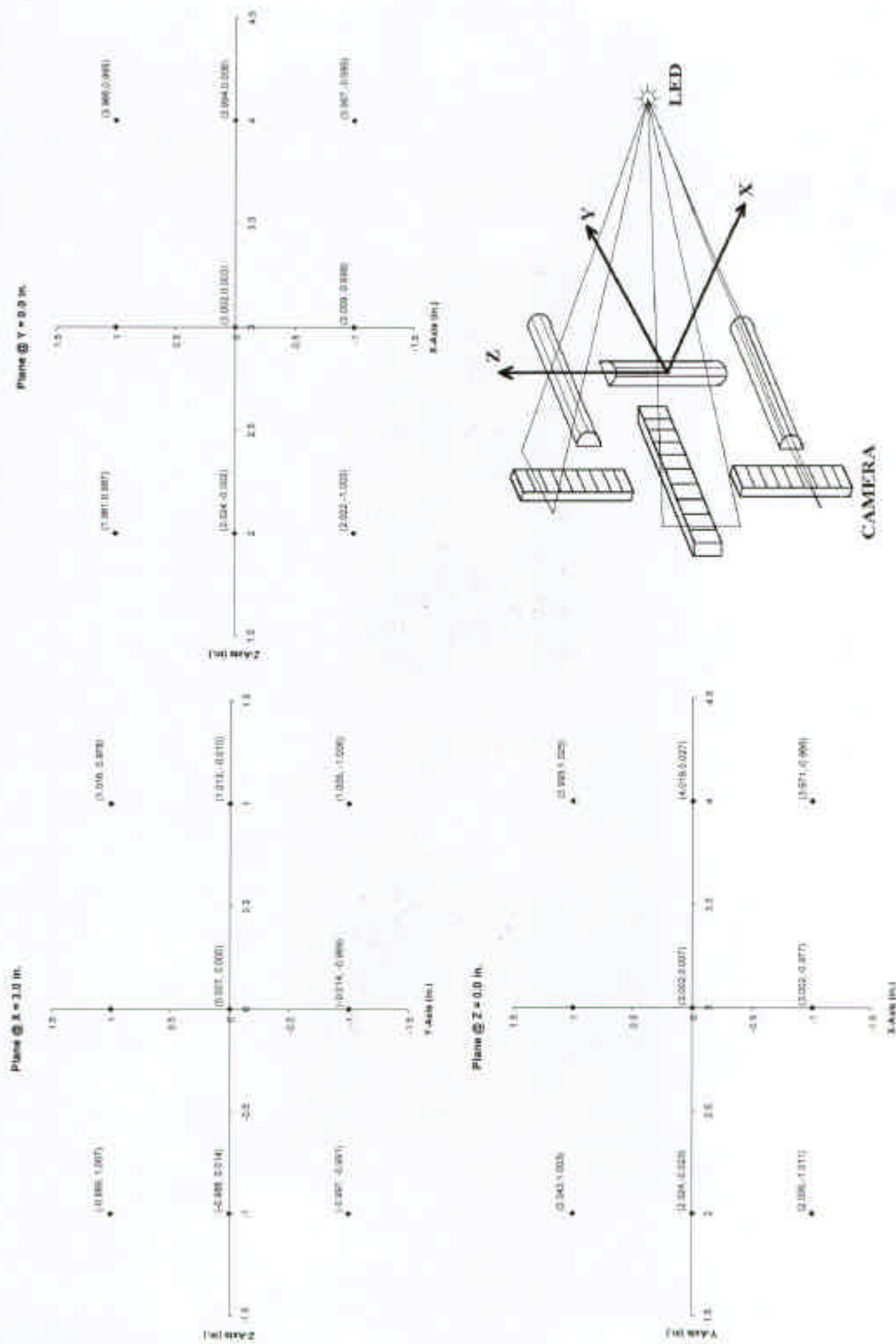


Figure 4. Static Testing of MITAS 8.0 Dynamic Testing on the Bench

LABORATORY DYNAMIC TESTING

Two testing apparatuses were utilized to assess the ability of MITAS to capture the motion of moving LED targets. The first test apparatus utilized a linear accelerator as the platform for the LED targets, with the MITAS rigidly mounted above, Figures 5 and 6. During the test the LED targets moved at high speed directly towards the sensor. Attached to the linear accelerator was a Lucas Control Systems linear variable differential transformer (LVDT), Model 2000 DC-EC, used to measure displacement. During the test, LVDT output was captured on a Tektronix TDS 360 Digital Real-Time oscilloscope.

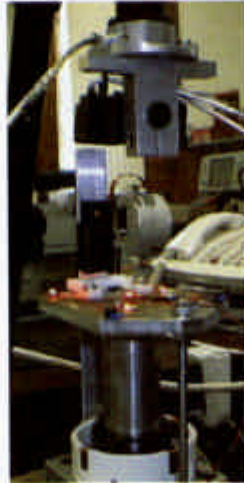


Figure 5. Dynamic Testing Utilizing Linear Accelerator



Figure 6. MITAS Mounting During Dynamic Testing

After performing a dynamic test, MITAS data was downloaded to a computer and post-processed to triangulate the positions of the LED targets. Using the time history of the triangulated positions, deflections along the axis of the test, are computed and compared to the LVDT. An example of this comparison is shown in Figure 7.

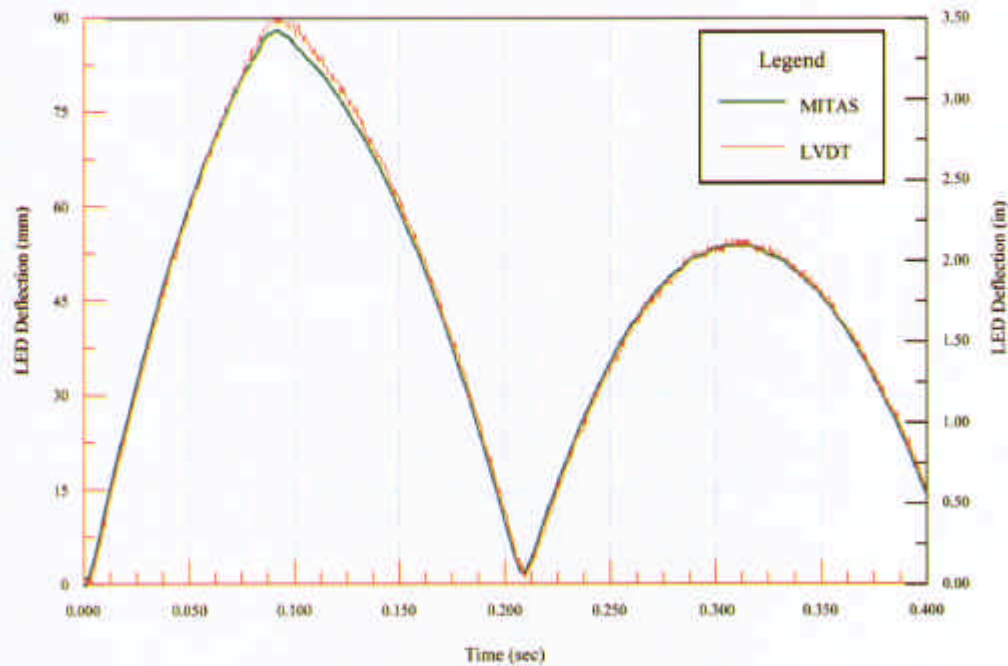


Figure 7. Dynamic Testing Comparison of MITAS to an LVDT

The second dynamic test apparatus, shown in Figure 8, consists of a LED attached to a spinning disc, which rotates in the YZ Plane of the MITAS. A modified Sherline Series 5400 variable speed miniature-milling machine performs the disc rotation. The milling machine has a tachometer attached to read revolutions per minute (RPM).



Figure 8. Dynamic Circular Motion Test Apparatus

Based on the position of the LED and a desired tangential velocity of 5 m/s, the milling machine was set to rotate at 1580 RPM. The circular motion was captured by the MITAS as shown by a plot of the resulting YZ coordinates in Figure 9. The first 100 milliseconds of motion are shown in

the plot, which results in overlapping circles. When the Y and Z coordinate positions are plotted with respect to time, they form two sinusoidal waves that are 90 degrees out of phase, shown in Figure 10.

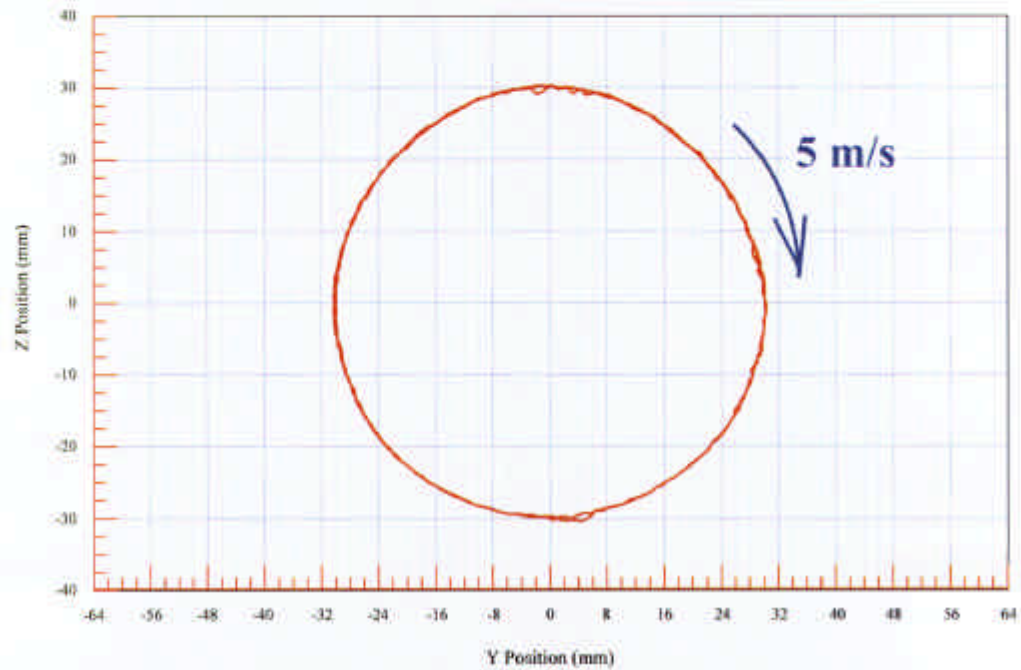


Figure 9. Dynamic Circular Motion Test at 5 Meters per Second – YZ Plane

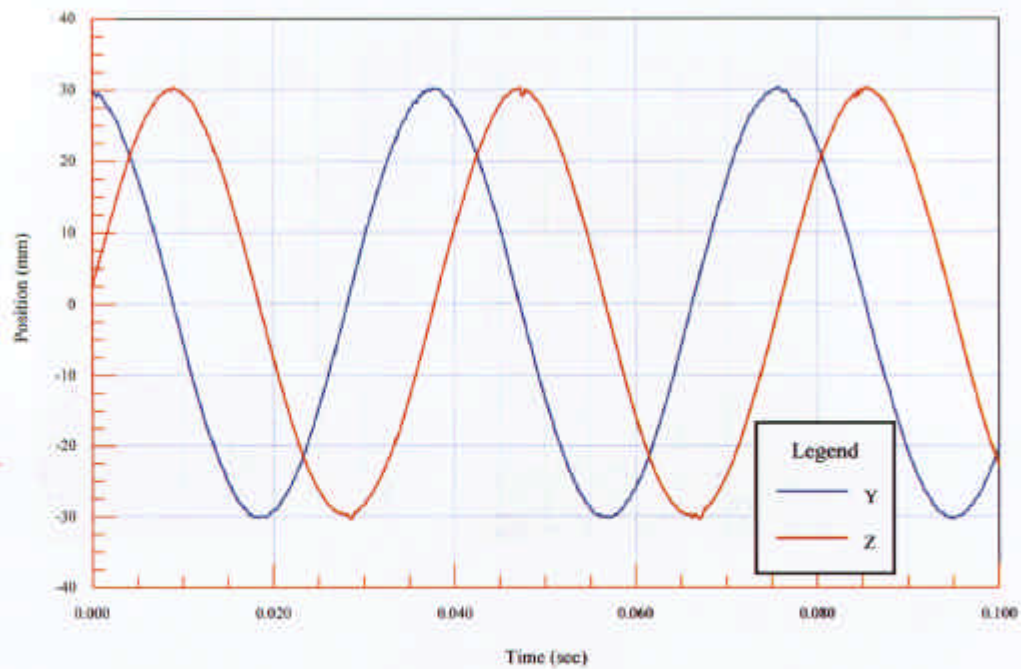


Figure 10. Dynamic Circular Motion Test at 5 Meters per Second – Position Vs. Time

The small perturbations that are seen in Figures 9 and 10 are most likely the result of imperfections of the bearings, imbalance of the rotor, or platform vibration in the milling machine.

STATIC TESTING INSTALLED IN THOR

For the static testing of MITAS within the THOR, CTI mounted three LED targets at locations numbers 1, 4 and 5 as labeled in Figure 2. In addition, CTI mounted a "Calibration LED" rigidly to the spine in view of the MITAS. The "Calibration LED" served as a fixed reference to ensure system operation and verify the location and orientation of the MITAS.

CTI designed an adjustable mount, Figure 11, which attaches to the spine and provides one linear and two angular degrees of freedom for the mounting of MITAS. Once MITAS has been properly aligned within the THOR the degrees of freedom are locked and the MITAS becomes rigidly attached, Figure 12.

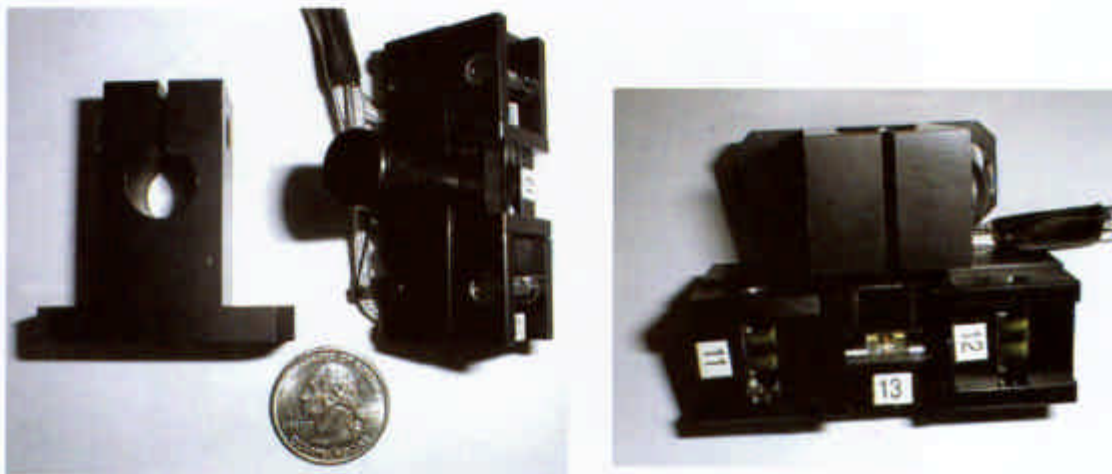


Figure 11. MITAS Adjustable Mount for THOR

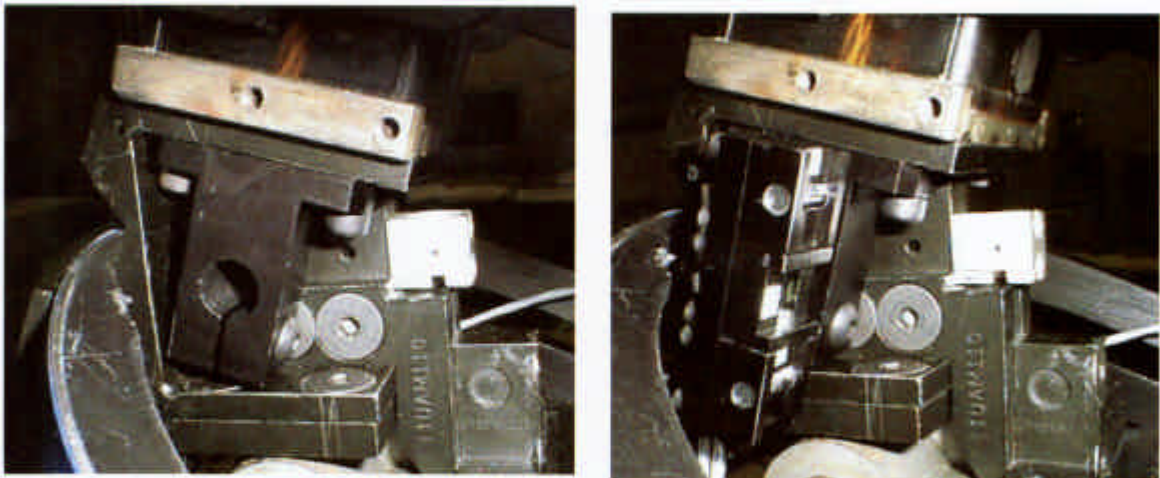


Figure 12. MITAS Mounted in THOR, Shown with Ribs 4 & 5 Removed

Once the MITAS was mounted and positioned within the THOR, the ribs were deflected in small increments by static loading. At each increment, the MITAS recorded the position of the LED targets to verify the field of view of the system. The ribs were deflected until interference occurred between the sternum and the spine. Based on these deflections, the field of view was verified for static loading along the x-axis.

DYNAMIC TESTING INSTALLED IN THOR

Dynamic testing at GESAC, Inc. using a standard THOR ATD and the CRUX device for measuring thoracic displacement, assessed the performance of MITAS. A device, developed by GESAC and shown in Figure 13, provided dynamic test conditions with a 152 mm impact face with radius edges and a total system mass of 23.4 kg. Impact with a target area on the manikin occurred within 50 mm of travel after the impact rod exited the spring accelerator. The upper and lower abdomen bags in the THOR manikin were removed to allow access to the CRUX and MITAS instrumentation and to provide a clear line-of-sight for the linear CCD sensor arrays.

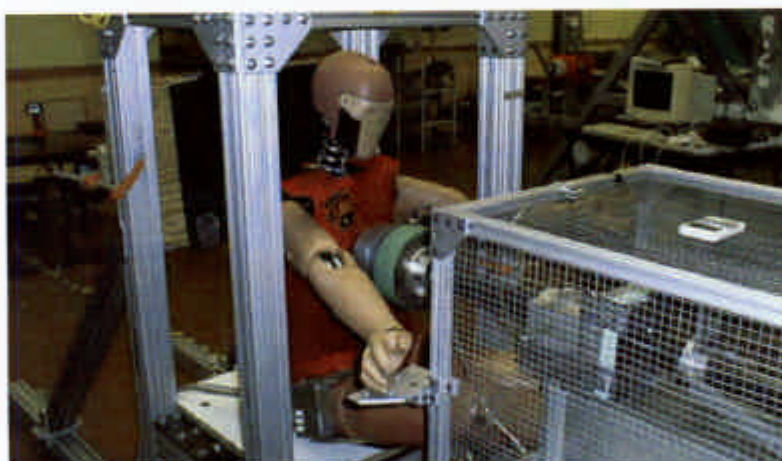


Figure 13. GESAC Impact Device with THOR Dummy

An autonomous data acquisition system provided by GESAC was used to acquire sampled data from an LVDT, accelerometer and load cell, which monitored the mechanical events associated with the CRUX. The processed LVDT signal provided a digital trigger signal to MITAS, which acquired digital pixel data of the multiple LED targets.

A summary of the dynamic test conditions is presented below in Table 1.

Table 1. DYNAMIC TEST CONDITION SUMMARY

Velocity (m/sec)	Impact Location	Impact Angle (°)	CRUX Location	No. of LEDs
2.1	R3	0	R3	1
4.8	R3	0	R3	1
2.0	R3	15	R3	1
4.7	R3	15	R3	1
7.0	R3	0	R3	1
7.0	R3	0	R3	1
4.5	R3	0	R3	1
2.0	R3	0	R3	2

Velocity (m/sec)	Impact Location	Impact Angle (°)	CRUX Location	No. of LEDs
4.6	R3	0	R3	2
2.0	R3	0	R3	3
7.0	R3	0	R3	3
2.0	R3	15	R3	2
4.5	R3	15	R3	2
1.5	R6	15	R6	1
1.5	R6	15	R6	2
1.5	R6	15	R6	2
6.7	R3	0	R3	3
11.0	R3	0	R3	3
11.75	R3	0	R3	3
4.5	R3	0	R6	3
4.5	R3	0	R6	3
4.5	R3	0	R6	3
4.5	R3	0	R6	3
4.5	R3	0	R6	3
4.5	R3	0	R6	3
4.5	R3	0	R6	3
4.5	R3	15	R6	3
4.5	R3	15	R6	3
4.5	R6	0	R6	3

A comparison of displacement along the dummy's x-axis is shown in Figure 14. The difference shown in the plot is due to the fact that the MITAS and CRUX are not measuring the same point, since the target LED was not able to attach directly to the CRUX measuring point.

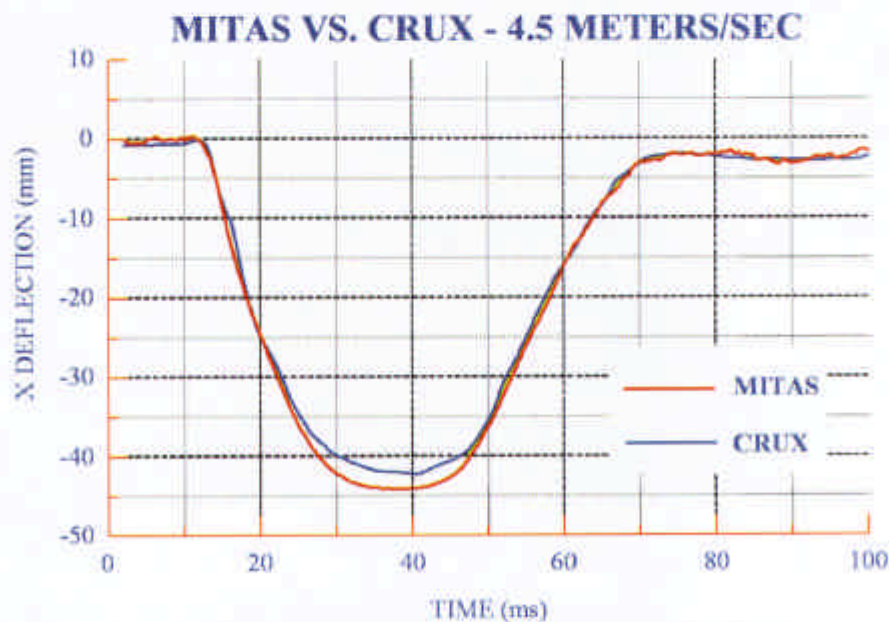


Figure 14. THOR X-Axis Deflection Comparison During Dynamic Test

CONCLUSIONS AND RECOMMENDATIONS

The Motion Imaging and Tracking Acquisition System (MITAS) project was initiated in September 2000 and the first field test at GESAC, Inc. occurred less than a year later. The CMOS sensor arrays, mechanical housing, and cylindrical COTS lenses represent a rapid, low-cost solution to this crucial subsystem. The CMOS sensor arrays performed without failure due to either mechanical shock and vibration or electrostatic discharge in the dynamic tests to date.

The analog CCD video signal, data conversion and digital logic was designed and constructed in less than six months and features a state-of-the-art data flow controller and non-volatile memory module using Commercial-off-the-Shelf (COTS) components. The MITAS electronic subsystems are modular, expandable, and acquire and store pixel data at rates greater than 5 MHz. They also performed without failure in all the dynamic tests to date.

Overall, the MITAS succeeded in capturing thoracic displacement within an anthropomorphic manikin. The MITAS was shown to have a higher bandwidth response to thoracic displacements than its electromechanical counterparts. The MITAS measured displacements, in general, matched well with the CRUX system measurements.

ACKNOWLEDGEMENTS

The National Transportation Biomechanics Research Center (NTBRC) of the National Highway Traffic Safety Administration (NHTSA) sponsored a portion of the research described in this report. The authors gratefully acknowledge the guidance and assistance given by Mr. Mark Haffner of NHTSA, whose insight and knowledge proved invaluable in the development of the MITAS. In addition, the authors thank Dr. N. Rangarajan, Dr. Tariq Shams, Mr. Dick Delbridge and Mr. David Beach of GESAC, Inc., the developers of THOR, who provided significant assistance in the dynamic testing of MITAS. Finally, the authors would also like to thank Mr. Donald DeCleene of Conrad Technologies, Inc. for guidance in interfacing MITAS with a current Anthropomorphic Test Device.

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- FOSTER et al, Hybrid III - A Biomechanically-Based Crash Test Dummy, *Proceedings 21st Stapp Car Crash Conference*, SAE Tech. Paper No. 770938, 1977, pp 975-1014

DISCUSSION

PAPER: Motion Imaging and Tracking Acquisition System (MITAS) for Measuring Chest Deflections in Crash Test Dummies

PRESENTER: *Mark Haffner, NHTSA*

QUESTION: *Guy Nusholtz, Daimler Chrysler*

Have you run any tests to evaluate its durability and reliability particularly in the violent type of situations we have in dummies?

ANSWER: Yes. You'll notice that the 12 meter per second tests were done with the cannon-mounted 55 lb. mass driven directly into the chest. As you well know, anterior thorax surface Gs can run as high as 750 to 800 Gs in aggressive bag slap conditions. One of the reasons for doing the pendulum testing was to verify that the LEDs, which of course are taking most of the grief, did survive. And no drop outs were seen, and LED currents were stable. Looking at the camera system and mounted optics, these parts are fully potted and are solid. You may recall that in 1991 Toyota reported an optical measurement system which used position sensing detectors, but they had mirrors in their system which were somewhat shock sensitive. In short, we think that the MITAS system will be extremely rugged.

Q: You've discussed adding it to THOR?

A: Yes.

Q: Have you thought about adding it to Hybrid III?

A: Absolutely. I'm sure that Conrad would be happy to hear from you. In addition, several other dummy and vehicle applications suggest themselves.

Q: *Steve Moss, First Technology*

Are you doing the processing on board with electronics or is it all off-board processing?

A: Currently, Steve, the processing is being done off-board on laptop. But in our eventual implementation, we think we will want to process on-board sled or on-board vehicle, to eliminate the necessity for additional processing steps later. So we would process raw sensor data immediately to X, Y, Z off-dummy, and store the numbers for interrogation and retrieval post-test.

